Research on Seismic Performance of Steel-Concrete Composite High-Rise Structures: Review, Challenges, and Emerging Trends

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Abstract- ***In recent years, the construction of high-rise buildings has become increasingly important due to urbanization and population growth in cities. Conventional reinforced concrete (RCC) structures have long been used; however, the need for faster construction, higher strength, and better seismic resilience drives the adoption of steel-concrete composite structural systems. These systems combine the compressive strength and stiffness of concrete with the tensile strength and ductility of steel, offering superior overall structural performance. Steel-concrete composite construction offers advantages like rapid construction speed, reduced structural weight, enhanced load-carrying capacity, and improved seismic resistance. Under earthquake loading, the synergy between steel and concrete helps in dissipating energy effectively, limiting lateral displacements, and enhancing ductility. This makes composite high-rise structures well-suited for seismic zones, offering better safety and serviceability. Research and practical applications in countries including China and India show that composite high-rise structures can be cost-effective and efficient solutions, incorporating advanced materials and modern design methods aligned with seismic design codes such as IS 1893 and relevant international standards.***

Keywords: Steel–concrete composite structures, high-rise buildings, seismic performance, composite columns, composite beams, earthquake resistance, performance-based design, damping systems

I. INTRODUCTION

Steel-concrete composite structures cover structural elements such as beams, slabs, and columns in which the best structural properties of each material are combined. Steel-concrete composite structures combine the strengths of both materials to create more efficient and robust building elements. By using steel for tension and concrete for compression, these structures are known for their high strength, stiffness, and fire resistance. Common components include composite beams, slabs, and columns, and they are used in high-rise buildings, bridges, and other resilient infrastructure projects

The term 'composite structures' refer to structures in which different materials such as timber, steel, concrete, and masonry are used together for construction. The most common type of composite construction is the use of steel and concrete to form steel-concrete composite structures. Steel-concrete composite structural members are known as economic members and have been used in construction for various structure types. It is a very well-known fact that steel members are susceptible to buckling, while their tensile strength is remarkable.

Steel-concrete composite structures generally exhibit superior seismic performance compared to traditional reinforced concrete (RCC) structures due to their enhanced stiffness, strength, and energy dissipation capabilities.

The fundamental concept of seismic performance in steel-concrete composite high-rise structures is the synergistic combination of steel's high tensile strength and ductility with concrete's high compressive strength and stiffness.

1. Composite Action: The key principle is ensuring the steel and concrete components act as a single, integrated unit, typically achieved through mechanical shear connectors. This ideal combination maximizes the benefits of both materials
2. Enhanced Strength and Stiffness: The composite elements, such as composite columns (concrete-filled steel tubes or concrete-encased steel sections) and composite shear walls, provide

increased load-bearing capacity and lateral stiffness, which helps in controlling overall and inter-story drift under seismic loads.

3. Ductility and Energy Dissipation: The inherent ductility of steel allows the structure to undergo significant inelastic deformations without catastrophic failure, while concrete contributes to damping and energy absorption. This ability to dissipate seismic energy is crucial for safety during a major earthquake.
4. "Strong Column-Weak Beam" Philosophy: A primary design principle is to ensure that columns remain intact, forcing plastic hinge formation (energy dissipation) to occur in the beams, which are easier to inspect and repair after an event.
5. Reduced Seismic Weight: Composite structures are often lighter than their RC counterparts, which naturally results in lower seismic forces acting on the building during an earthquake (seismic force is proportional to mass)

II. METHODOLOGY

1) A thorough literature review to understand the seismic evaluation structures and application of Steel-Concrete Composite High-Rise Structures
2) Selection of the dimensions of Existing High-Rise Structures.
3) Model the selected in computer software ETABS
4) Carry out modal analysis to obtain the dynamic properties of the High-Rise Structures and input parameters for seismic analysis of the High-Rise Structures.
5) Carry out seismic analysis of the High-Rise Structures and arrive at a conclusion.

A. Problem Statement

The selected project involves analysing the seismic performance of a G+21 residential high-rise structure located in Pune (Seismic Zone III), consisting of 1 Basement, 1 Podium, Ground Floor, 19 Upper Floors, and a Terrace Floor. Due to its height and functional layout, the building is subjected to significant lateral forces during earthquakes, making it essential to evaluate its behaviour using an efficient structural system. Traditional RCC systems often face limitations in stiffness and ductility for tall structures; therefore, steel–concrete composite elements are considered as an alternative to enhance seismic resistance.

The problem addressed in this study is to assess the seismic performance, lateral load behaviour, drift control, and overall stability of this composite high-rise building using ETABS under various realistic loading conditions. The analysis aims to understand how composite members improve structural performance when compared to conventional systems for high-rise residential buildings in Indian seismic conditions.

Table.1: Functional Requirement of the building

Sr No	Floor Level	Floor to Floor Height (m)	Functional Uses
1	Basement 1	1.625	Parking
2	Podium 1	3.15	Parking
3	Ground Floor	3.15	Parking
4	First Floor	3.00	Residential
5	2nd to 19th	2.95	Residential
6	Terrace Floor	2.85	Solar Panel

- Composite Beam = 350 × 450 mm with embedded ISMB steel section.
- Composite Column = 900 × 350 mm with embedded ISWB steel section.
- Slab Thickness = 150 mm

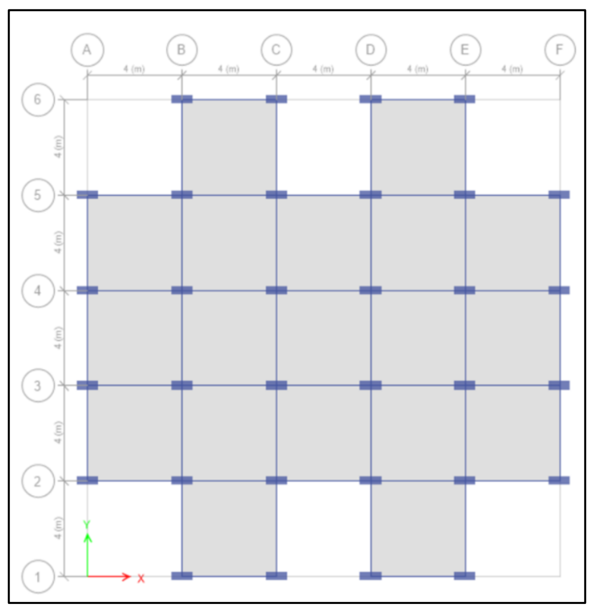


Fig 1 Plan of Building

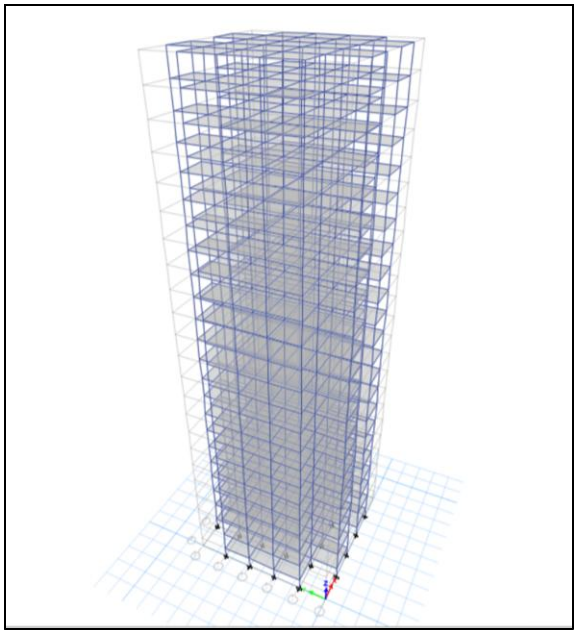
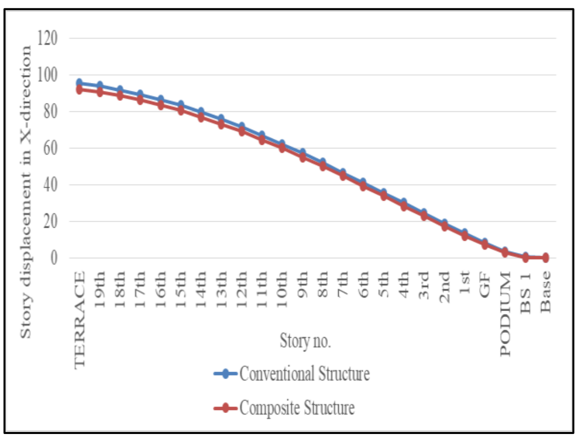


Fig: 2 3D view of G+19 floors building

III. RESULTS AND DISCUSSION

A. Story displacement in X direction.

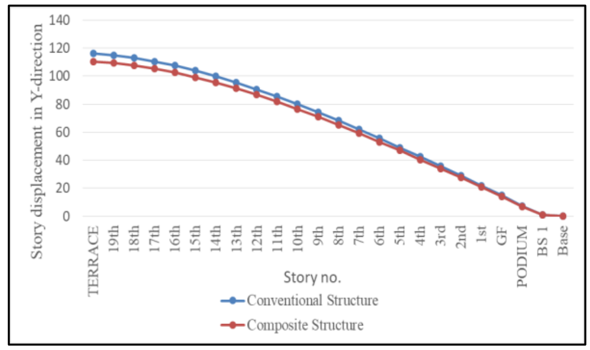


Graph 1 Displacement in X direction

The storey displacement results in the X-direction indicate that the displacement values gradually decrease from the top storey towards the base in both the conventional RCC structure and the Steel–Concrete Composite structure. The conventional RCC structure exhibited the highest displacement values at all storey levels, with a maximum displacement of 95.601 mm at the top storey and a minimum displacement of 0.508 mm at the base storey. In comparison, the Steel–Concrete Composite structure showed lower displacement values, with a maximum displacement of 92.177 mm at the top storey and a minimum displacement of 0.434 mm at the base storey.

The reduction in displacement in the composite structure indicates improved lateral stiffness and better seismic performance due to the composite action between steel and concrete members. The embedded steel sections enhanced the rigidity and ductility of the structure, thereby reducing lateral deformation under earthquake loading.

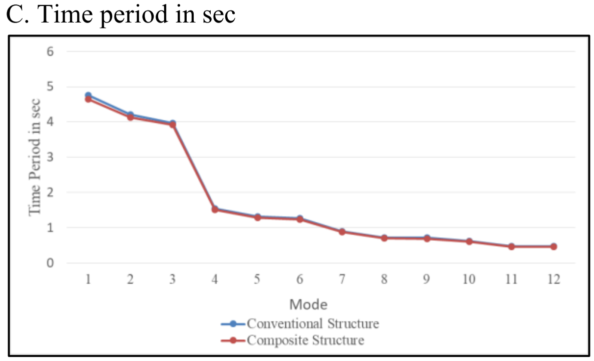
B. Story displacement in Y direction



Graph 2 Displacement in Y direction

The storey displacement results in the Y-direction indicate that the displacement values decrease gradually from the top storey towards the base in both the conventional RCC structure and the Steel–Concrete Composite structure. The conventional RCC structure exhibited higher displacement values throughout the height of the building, with a maximum displacement of 116.172 mm at the top storey and a minimum displacement of 1.071 mm at the base storey. In comparison, the Steel–Concrete Composite structure showed reduced displacement values, with a maximum displacement of 110.381 mm at the top storey and a minimum displacement of 0.993 mm at the base storey.

C. Time period in sec



Graph 3 Time period in sec.

The modal time period results indicate that both the RCC structure and the Steel–Concrete Composite structure show a gradual decrease in time period from the fundamental mode to higher modes. The conventional RCC structure recorded a maximum fundamental time period of 4.762 sec, which gradually decreased to 0.474 sec in higher modes.

In comparison, the Steel–Concrete Composite structure exhibited a slightly lower fundamental time period of 4.652 sec, which further decreased to 0.458 sec in higher modes.

The lower time period observed in the composite structure indicates higher lateral stiffness and improved structural rigidity compared to the conventional RCC structure. The presence of embedded steel sections within the concrete members enhanced the stiffness of the structure, thereby reducing the natural time period.

IV. CONCLUSION

- The analysis and design of the G+19 Steel–Concrete Composite Building modeled in ETABS showed that the composite structural system performs efficiently under gravity and seismic loading conditions. The use of composite beams and composite columns significantly improved the overall stiffness and load carrying capacity of the structure while reducing the self-weight compared to a conventional RCC structure.
- Composite structures exhibit significantly reduced base shear, lateral displacement, and inter-storey drift under seismic loading, indicating enhanced seismic resilience.
- Steel-concrete composite high-rise buildings offer a promising solution for seismic-resistant construction, ensuring improved safety, serviceability, and economic efficiency
- Spectral Displacement Demand &Spectral Displacement Capacity is calculated by conducting Nonlinear Static (Pushover) Analysis.

V. RECOMMENDATION

- Response Spectrum Analysis and P-Delta Analysis should be performed for all high-rise composite buildings to accurately capture dynamic effects.
- RCC shear walls or central core walls should be provided to improve lateral stiffness and reduce storey drift.
- Higher concrete grades such as M40 or M50 should be adopted for high-rise composite columns.
- Composite construction using embedded steel sections is recommended for reducing structural weight and improving seismic performance.

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IS Codes:

- IS 456:2000 – Plain and Reinforced Concrete – Code of Practice
- IS 875 (Part 1 & 2):1987 – Dead and Live Load Calculations
- IS 1786:2008 – High Strength Deformed Steel Bars for Concrete Reinforcement